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Mind and Hand:

Early Scientific Instruments from al-Andalus and 'Abbas ibn Firnas in the Cordoban Umayyad Court

This essay explores a symbiotic relationship between design, visual culture, and the exact sciences, which is revealed by early Islamic scientific instruments from al-Andalus and by the career of 'Abbas ibn Firnas (d. 887).¹ A celebrated courtier and polymath in the Umayyad court of Córdoba, today Ibn Firnas is celebrated as an early scientist, one of the great figures of the early Islamic scientific revolution, and is best known for conducting an early aeronautics experiment that has been considered a milestone in the history of human flight. Though remembered today for his aeronautics experiment, it is his reputation as evoked by Andalusí intellectuals in the tenth and eleventh centuries that underscores the connection between intellectual culture and craft evident in the surviving objects.

Key to the argument I wish to make here, is Ibn Firnas' fame, according to the Cordoban court chronicle, as the first designer and maker of precision scientific instruments for the Umayyad rulers of ninth century Córdoba. Neither historians of art nor of science have fully explored the implications of his reputation among eleventh-century intellectuals as the wellspring of an Andalusí tradition of fine scientific instrumentation. This essay considers the Arabic account of Ibn Firnas as a maker of such objects, alongside early extant instruments, exploring what this reveals about connections between elite intellectual culture and craft, about science and artmaking, in Umayyad Córdoba

and the early Islamic lands. This essay argues that considering these objects in tandem with Ibn Hayyan's account, which is the earliest and fullest account of Ibn Firnas' career, brings to the fore the phenomenon of intellectuals, specifically those working in the exact sciences – astronomers, mathematicians, and engineers – as 'makers' of early Islamic visual culture.

Remembering a ninth century polymath

The longest and most substantive source for this polymath's career is the Cordoban court chronicle, compiled by the historian Ibn Hayyan (d. 1076). First identified in the 1930s, the Arabic manuscript (preserved in Madrid) of the volume devoted to the ninth century dropped out of view following its initial discovery. It was believed lost until its rediscovery and publication in facsimile in 1999 by Joaquín Vallvé Bermejo. 'Abbas Ibn Firnas, at least from the perspective of this earliest and most substantive Arabic source that tells us about his life and career, was arguably one of the most famous intellectuals of ninth-century al-Andalus. Ibn Hayyan (d. 1076) and his sources, who comprise a who's who of ninth and tenth-century court intellectual and religious elites, sketch a picture of a polymath whose knowledge of both ancient sciences as well as "modern" ones valued by ninth-century learned elites in Islamic societies was viewed as second to none by those who knew him. The earliest and most substantive account of Ibn Firnas's career appears in the Arabic chronicle compiled by the eleventh century Cordoban court historian Ibn Hayyan (d. 1076). The second volume of Ibn Hayyan's chronicle, the *Muqtabas* (or *Muqtabas*), in which the account of Ibn

Firnas's career is preserved, has been aptly described by Manuela Marín as the "Maltese Falcon" of Andalusí studies, an allusion to its rarity, its value as a historical document, and the colorful story of its modern disappearance and subsequent rediscovery.² The unique Arabic manuscript is an incomplete copy of the annals of the Cordoban emirs al-Hakam I and 'Abd al-Rahman II, covering the period between 796 - 847. It first came to the attention of European scholars in the early twentieth century when it was identified by Arabist Evariste Lévi-Provençal (d. 1956) in the library of the Qarawiyyin mosque in Fes, apparently in the 1930s.³ Lévi-Provençal and the Arabist Emilio García Gómez (d. 1995) published translations extracted from the manuscript in the 1950s and were working on a critical edition of the text, which never materialized. Following the death of both scholars the manuscript dropped out of view and was believed lost for decades, taking on an almost mythical status, until Joaquín Vallvé Bermejo rediscovered it in García Gómez's papers posthumously and published it in facsimile in 1999.⁴ The publication of the facsimile edition was followed by a critical Spanish translation by Federico Corriente in 2001 and a critical Arabic edition by Mahmud Makki in 2003.⁵

The manuscript is not securely dated, as it is missing its beginning and ending folios (it begins at folio 88r and ends with 188v). Nevertheless, the Kufic calligraphy and its overall appearance, represented in the three leaves containing the bulk of the account of Ibn Firnas's career, are generally in keeping with other medieval manuscripts from the Islamic west.⁶ It is not out of the realm of possibility that the Madrid manuscript was created around the fourteenth century,

as it appears similar to other fourteenth century manuscripts from the Maghrib.⁷ Until the rediscovery of Ibn Hayyan's lost volume, historians had to rely on abbreviated accounts about 'Abbas Ibn Firnas which were composed by later medieval and early modern authors. The most influential biography was penned in the seventeenth century, by the Maghribi intellectual Ahmad ibn Muhammad al-Maqqari (died c. 1632). Al-Maqqari wrote an important history of Islamic Spain based on earlier sources, many of which are now lost, which was edited and published by Dozy, the great nineteenth century Orientalist scholar.⁸ Al-Maqqari's history has been especially influential in modern Anglo-American contexts because in the nineteenth century, at the height of Anglo-European fascination with Spain and a romanticized "Moorish" past going back to at least the seventeenth century,⁹ the Spanish Arabist and diplomat Pascual de Gayangos penned an abridged English version of al-Maqqari's text as part of his History of the Mohammedan dynasties in Spain, which has remained popular and important since its publication in 1840-43.¹⁰ Gayangos' version has a distinctively nineteenth century Victorian flavor, in keeping with the tastes and conventions of his time and place, and his Anglophone audience, and which makes it distinct from the history composed by al-Maqqari for his audience of seventeenth century Islamic intellectuals.¹¹ Despite the clear emphasis al-Maqqari, in the seventeenth century, and Gayangos, in the nineteenth century, placed on 'Abbas Ibn Firnas as an intellectual of early Islamic al-Andalus, both treatments of him are brief.

Writing in the eleventh century, Ibn Hayyan and his tenth-century sources, by contrast, provide a much fuller portrait of the man. At least twelve full

manuscript pages are devoted to ‘Abbas Ibn Firnas, divided across the various volumes of the *Muqtabas*.¹² This amount of space compares favorably to the number of pages devoted in the chronicle to Ziryab, perhaps the most famous musician in the history of Islamic civilization, who was a contemporary of ‘Abbas Ibn Firnas and like him a boon companion (*nadīm*/pl. *nidām*, *nudamā*’, *nudmān*) and something of a celebrity in Cordoban court society.¹³

Ibn Hayyan begins his account of Ibn Firnas’s career by mentioning his skill as an inventor, designer, and maker, and emphasizing his ability to invent and to innovate in particular:

In the time of the emir al-Hakam appeared ‘Abbas ibn Firnas, the wise man (*ḥakīmu*) of al-Andalus who superseded all others in the number of skills and arts (*al-adawāti wa-l-funūnī*). He was ... full of inventiveness (*ḥasana al-ikhtirā’i*) and of the capacity for innovation (*kathīra al-ibdā’i*).¹⁴

Later in the passage he returns to this theme of the polymath’s inventiveness and innovative tendencies as evidenced by instruments Ibn Firnas is said to have designed and made. Reporting the words of a tenth-century Cordoban court poet, regarding these objects:

I read the following words of the poet ‘Ubada, handwritten by the poet himself: He was the one who made in al-Andalus the clepsydra (*alladhī ‘amila bi-l-Andalūsi al-minqānata*) for knowing the hour, which he sent to the emir Muhammad, grandson of the emir Al-Hakam... Before that ‘Abbas had also made an armillary sphere (*wa-‘amila ‘Abbassun ayḍan min qablu, dhāta al-ḥalaqi...*) for the emir ‘Abd al-Rahman ibn Al-Hakam,

which he sent ...¹⁵

The anecdote establishes a chronology, albeit a skeletal one, for considering ‘Abbas Ibn Firnas’s activities as a maker. It tells us that Ibn Firnas was making instruments sometime in the three decades between 822–852, which is when ‘Abd al-Rahman ibn al-Hakam (‘Abd al-Rahman II) reigned as emir of al-Andalus. It was for this ruler that Ibn Firnas made the first of the instruments, an armillary sphere. Armillary spheres were an important type of astronomical tool known from antiquity and used to model the heavenly spheres and to carry out various celestial observations and calculations. No armillary spheres, whether from al-Andalus or elsewhere, have survived from the medieval period that might give us a sense of this device’s appearance, its scale, materials, or visual language, although the device is discussed in textual sources, including Ptolemy, whose writings were available and revered in this period.¹⁶ Its significance as a tool for understanding celestial motions comes across clearly in the Abbasid astronomer al-Farghani’s (Baghdad, ca. 856) treatise on the astrolabe, which is the earliest Arabic work on the topic. In this work he states that “the observational instrument with which they [scholars of mathematical astronomy] achieved most was the instrument that is called the armillary sphere [*dhat al-halaq*].¹⁷ Al- Farghani emphasized the utility of the instrument as a means to understand the celestial spheres and their motions, and the origins of its design in both mathematical theory and observation, making clear the interconnectedness of mathematics, astronomy, and design. One of the notable features of Al- Farghani’s treatise is that it provides the information that

medieval intellectuals would have needed in order to draw the circles and arcs on astrolabes – in other words, to design a crucial aspect of their visual program. In the preface to his treatise on the astrolabe al-Farghani explains that he has written the work in order to provide visual, graphic proof of the astrolabe's correctness, in order to refute any doubts as to the rationale informing the design of the instruments. He states:

I wrote a comprehensive book in which I demonstrate the correctness of the form of the astrolabe ... the obtaining of the sizes of all the circles that are formed on the astrolabe to replace the sphere of the heavens, the description of their construction ...¹⁸

Al-Farghani is emphasizing the application of geometry to the design of a two-dimensional representation of the universe. It takes great creativity and imagination to conceive of representing the universe in the form of an instrument that one can hold in the palm of one's hand. The link between mathematics, imagination, three-dimensional space and geometrical objects evident in such texts illuminates how and why intellectuals working in the exact sciences were able to translate that knowledge into craft and architecture.¹⁹

The tenth-century philosopher al-Farabi discusses the Arabic term *takhyil*, which designates the imaginary in classical Arabic poetics, and which like mathematics, can be related to medieval Islamic understanding of the imagination and creativity.²⁰ Al-Farabi identifies two modes of verbal representation encompassed by the term. The first mode discussed by al-Farabi is a direct representation (in other words, a representation that aspires to

realism), while the second mode is one that is removed from the object it represents potentially by multiple levels. According to al-Farabi, “many people believe that the more removed the imitation is from its subject matter the better and more complete it is in comparison with a more direct representation of a subject matter. They also hold that the creator ... of this [latter] description is more entitled to the act of imitation, more skilled in the craft and more proficient in its practice.”²¹ Al-Farabi was speaking about literary representation, and one could argue therefore that the realm of literature and the realm of the material and the visual, as pertains in the case of these precision instruments, may not be entirely commensurable.²² Yet, if we entertain the notion that crafting poetry and crafting visual and material models and representations of the heavens were compatible pursuits for caliphal intellectuals, perhaps al-Farabi’s observations provide a valuable clue as to how scientific instruments and wondrous devices may have been understood and valued by those who designed, made, and used them in their own day.

Returning to the Cordoban chronicle, it might seem strange that the source of our information on Ibn Firnas’s scientific instruments was a court poet, but in fact science and poetry are very closely connected in the chronicle’s account of our polymath’s career. At the very outset of the account, Ibn Hayyan characterizes him as “a brilliant poet” (*shā‘iran mufalliḡan*) and an “inspired and truthful astrologer” (*munajjiman maṭbū‘an muwaffaḡan*) it is important to note that in the ninth century, astronomy and astrology were nearly indistinguishable.²³ Ibn Hayyan cites the tenth-century Cordoban historian ‘Isa ibn Ahmad al-Razi, who

likewise observed that our polymath was remunerated for his skills in both science and poetry: “The emir ‘Abd-al-Rahman [‘Abd al-Rahman II] gave ‘Abbas two allowances: one for poetry and another for astrology (*li-l-tanjīmi*)²⁴ and drew him close as a boon companion.”²⁵ Likewise, ‘Ubada the poet begins his anecdote about Ibn Firnas and the instruments he made by noting that the polymath was known for having ‘excelled in all the sciences, ancient and modern (*al-‘ulūmi al-qadīmati wa-l-muḥdathati*). He dominated Arabic and was adept at making good poetry, excelling as well in philosophy, astronomy, and astrology.’²⁶ But it is the lines of poetry preserved in ‘Ubada’s anecdote—lines which he reports that Ibn Firnas composed and engraved himself on the two instruments—that fully illustrate the close links between science, intellect, and craft in the court at Córdoba:

‘Abbas had also made an armillary sphere (*wa-‘amila ‘Abbassun ayḍan min qablu, dhāta al-ḥalaqi*) for the emir ‘Abd al-Rahman ibn Al-Hakam, which he sent, inscribing upon it (*wa-kataba ma‘ahā*) [kamil]:

Complete is the instrument (*min ālatin*) that was commissioned of me

That great philosophers could not achieve, save for me;

If Ptolemy had been successful in doing so,

I wouldn’t be occupying myself with the tables of the Qanun²⁷

And if the sun was seen on its horizon,

It would be sending its measured light,

And the lunar mansions (*manāzilu al-qamari*), hidden to all eyes

with the horoscope of each moment (*dūna al-‘uyūni li-kulli ṭāli‘ ḥīnī*),

They would see during the day, the same as they appear

In the night, in its deep darkness²⁸

The poetry inscribed on the armillary sphere thus has the instrument speaking in the voice of its maker. In these lines Ibn Firnas’s personality shines through vividly, in his boast that in the instrument’s creation he had achieved something which “great philosophers,” including Ptolemy himself, were incapable.

‘Ubada tells us that the next instrument for which ‘Abbas Ibn Firnas was known in court was a waterclock, which he made for Muhammad I (r. 852–886), the ruler who succeeded al-Hakam I to the throne as emir of al-Andalus. At the beginning of his account of Ibn Firnas’s career, Ibn Hayyan adds to the impression that our polymath was famous for having made the waterclock. He notes that Ibn Firnas was the first “to discover intricate issues, fabricating with neither plan nor model the instrument known as clepsydra (*minqānah*) to tell the time...”²⁹ The implicit emphasis here is on the ingenuity and technical know-how Ibn Firnas possessed in order to have been able to design and build the waterclock.³⁰ Although we know of Ibn Firnas’s instrument, and therefore an early Andalusī engagement with the technology only from this Arabic text, this in itself is notable; Ibn Hayyan’s chronicle is the earliest Arabic textual reference to waterclocks, which became arguably the most important type of device in the medieval Islamic technological landscape.³¹ Medieval Andalusī waterclocks operated by means of transferring water, or in some cases mercury, via large outflow clepsydras (instruments known from antiquity that measured time using

the flow of water) with concentric siphons, which in turn transferred power to automata via mechanisms including complex gearing.³²

Whereas the armillary sphere is made to speak with the voice of its maker, the poetry that the chronicle tells us Ibn Firnas engraved on the waterclock is composed as if the instrument itself were addressing the beholder:

He sent to the emir Muhammad, grandson of the emir Al-Hakam,
engraving on it (*wa-naqasha fihā*) some verses of his that said [*tawīl*]:

I am the best instrument (*khayru adāti*) for religion,
When you (pl.) don't know the moment of each prayer,
When one cannot see for oneself the sun in the day, nor
the stars in nights of deep darkness;
For the blessing of Muhammad, imam of the Muslims,
With me the moments of prayer are clear.³³

Thus, the inscribed poetry has this water clock claiming for itself a useful religious function as a means of ascertaining correct prayer times without making celestial observations.

That Ibn Firnas composed and inscribed poetry on both the instruments he designed and created for the Umayyad ruler is striking as an early instance of Andalusī 'speaking' objects. It suggests a ninth-century Iberian parallel to epigrams attested on Byzantine objects.³⁴ The poetic conceit that creates a speaking object has a rich history in the art and architecture of al-Andalus, of course.³⁵ The most celebrated example is the carved ivory pyxis on display in the Metropolitan Museum of Art, whose inscription has the object describing its own

beauty and function to the viewer: “The sight I offer is the fairest, the firm breast of a delicate girl. Beauty has invested me with splendid raiment, which makes a display of jewels. I am a receptacle for musk, camphor, and ambergris.”³⁶ (Fig. 1)

The same use of inscriptions to give voice to instruments, allowing them to “speak” with their own voice as well as with the voice of their makers, appears in two unique thirteenth-century devices made later in the eastern reaches of the empire. The first is a geared astrolabe, preserved in Oxford, and likely made in Isfahan. It bears a long inscription bordering its rear face, in which the instrument – like those of Ibn Firnas – speaks with the proud voice of the maker, explaining its functions and features to the viewer/user, and then proclaiming, “this disc is the product of the endeavour of someone learned in the technical arts, which are based on precision and scientific proof.”³⁷

Just as Ibn Firnas’s water clock inscription juxtaposed theological sentiments side by side with scientific concerns, the inscription on the geared astrolabe likewise alludes to the inextricability of medieval Islamic science and faith, stating “behold the disc! It will show you many of the wonders that prove the wisdom of the Merciful; its different motions are by virtue of a single mover, and it has meanings going beyond all meanings.”

A second extant device of the caliphal age that “speaks,” as Ibn Firnas’s creations did, is an instrument for the divinatory practice of geomancy (*‘ilm al-raml* (‘the science of the sand’) preserved in the British Museum.³⁸ Along with numerous inscriptions explaining how to use the device for divination, the maker decorated this device with poetic inscriptions that allude to religious and

supernatural themes. Framing the central dial at the lower left and right respectively are the following poetic inscriptions, in which the device speaks in the first person: “I am the revealer of secrets; in me are marvels of wisdom and strange and hidden things.” In these lines the object speaks directly to the viewer about its own efficacious power. Most striking indeed are these words, inscribed just below the central dial: “from my intricacies there comes about insight superior to books concerned with the study of the art.” Here the device speaks in order to insist on its own superiority to books, to the written word, as a means of obtaining knowledge.

Despite having been crafted later and in courts and contexts far removed from those of ninth century Córdoba, these two “speaking” objects, when considered together with ‘Ubada’s anecdote on Ibn Firnas’s armillary sphere and waterclock, makes it clear that caliphal intellectuals could and did design and craft objects of science, which participated in (or indeed shaped) Islamic court literary as well as visual modes.

The earliest Andalusí instruments

Turning to the earliest extant objects from Córdoba and al-Andalus, these likewise offer a clear sense of scientific instruments as works of art as well as intellect.³⁹ Three of the earliest precision instruments that have survived from Islamic Spain, comprising a group of astrolabes and one celestial globe, were made at approximately the same historical moment that Ibn Hayyan was compiling his account of Ibn Firnas’s career in the Cordoban court chronicle.

These early astronomical instruments confirm the impression that in al-Andalus, science and visual culture were closely intertwined by the opening decades of the eleventh century. I will focus on the astrolabes. Of the thirty-four astrolabes that have survived from medieval al-Andalus, four date to the Umayyad period, with an additional nine from the taifa period.⁴⁰

The objects I will discuss below are preserved today in Edinburgh and Madrid. Along with other early astrolabes and other precision instruments preserved in museum collections elsewhere in Europe, the United States, and the Middle East, they provide the clearest visual evidence of the intimate connections between science, court culture, design, and craft to which Ibn Firnas's career as instrument maker and court intellectual alert us. They bear eloquent witness to an early Andalusí tradition of design and invention. The wellspring of that tradition, at least as we can perceive it through the eyes of Andalusí intellectuals of the tenth and eleventh century as conveyed in the court chronicle, was 'Abbas Ibn Firnas.

Astrolabes are analogue computers, meant to make it easier for the user to carry out a variety of mathematical functions related to astronomical timekeeping.⁴¹ They are related to armillary spheres in that they represent a model of the heavens and can be used for some of the same mathematical and astronomical observations and calculations. Historians of science describe astrolabes as models of the universe that can be held in the hand, and this sense of the object as an abstract representation is key to keep in mind in considering the creativity and formal, visual choices, quite apart from the technical

knowledge, that a maker would bring to the task of designing and creating such an object.⁴²

These instruments constitute the earliest and most abundant type of instruments to survive from the medieval Islamic lands. Indeed, the fact that so many finely crafted metalwork astrolabes survive—preserved today in both scientific and art collections around the globe—deserves comment, since there is no particular reason why astrolabes have to be crafted as fine metal ware objects. They were, and are, also made in a more utilitarian mode out of less durable and expensive materials, such as paper and wood. It may be that the abundance of instruments reflects the limited period – about seventy years -- for which an astrolabe could function with precision, due to the motions of the celestial bodies over time.⁴³ But astrolabes are relatively easily updated to keep the instruments accurate, and there are a number of examples of astrolabes fitted with new retes long after their initial facture in order to address this issue.

The abundance of medieval Islamic examples bears witness to a deep engagement, on the part of early Islamic instrument makers and users, with materiality and visuality. Brass, the alloy used for Islamic astrolabes, is a perfect material for precision instrumentation due to its hardness and the precision with which it could be engraved. But besides its practical benefits, the golden appearance of a fine brass object is part of its undeniable visual appeal. Besides issues of practicality, the abundance of astrolabes speaks as much to the intimate connections between the intellect and matters of art, craft, materiality, and visuality that the chronicle's account of Ibn Firnas's career likewise reveals.

As Kunitschz has observed, “an instrument is the sort of curiosity that attracts the attention of a wider audience than tables in learned treatises which may even shy people off.”⁴⁴

While the chronicle does not state that Ibn Firnas himself made or designed astrolabes, his official salaried position as court astronomer makes it highly likely that he knew and used such instruments, which draw on much the same mathematical and astronomical knowledge used to construct armillary spheres. In any case, because astrolabes do constitute our earliest examples of early precision instruments that are also works of art, it is worth examining the earliest Andalusí examples closely, and to consider what they reveal about the entanglements between science and craft, which Ibn Firnas’s career exemplifies.

On display in the Museo Arqueológico Nacional, Madrid is an eleventh-century astrolabe whose age, monumental size, fine craftsmanship, and elaborate decoration are outstanding, especially given the relative rarity of fine Islamic metalwork before the twelfth century.⁴⁵ (Figs. 2-3) This instrument is arguably the most impressive work of science and art to have survived from the early Islamic west.⁴⁶ The Madrid instrument measures 24.2 cm in diameter and is constructed of three layers of brass measuring 1.9 cm.

The surfaces of the astrolabe are inscribed throughout with elegant Kufic inscriptions. (Fig. 4) Most important for this discussion is the inscription placed in a prominent position at the top and center of its obverse face. Historians of science understand this inscription to be the signature of the instrument’s maker, and it also provides the exact time and place of its creation: “made by (*sana ‘a*)

Ibrahim ibn Sa'īd al-Sahli, in the city of Toledo in [the month of] Shawwal AH 459 [June/July 1067 AD]."⁴⁷ (Figs. 5-6). The Arabic inscription is carefully worked in Kufic calligraphy, which was favoured before the twelfth century for important official inscriptions, as well as in the luxurious tenth-century Qur'an manuscripts produced across the Islamic empire. Along with the signature inscription, the rear face of the astrolabe is inscribed with calendar scales, four quadrants, circles indicating signs of the zodiac in Arabic, and circles indicating days of the months.

Six interchangeable plates, which fit within the body, or mater, of the astrolabe, are inscribed front and back with the names and latitudes of important Islamic cities, both east and west: Mecca, Medina, Baghdad, and Mosul appear along with Córdoba, Toledo, Seville, and Zaragoza, among others. (Figs. 4, 7) Besides the names of the cities and their latitudes these plates are inscribed with carefully worked arcs indicating prayer times and unequal hours. Adding to the visual appeal of the instrument's elegantly-worked inscriptions, the brass alloy would have had the rich appearance of gold when new.

The rete, or movable grid, used to mark the positions of stars, features elegantly curved pointers for twenty-eight stars, and is engraved with the names and symbols of the constellations of the zodiac circle. These are normally not found on the earliest eastern astrolabes, but do appear on later European instruments. The rete also features a striking framework of cusped arches to enclose and highlight slender, curved pointers for three important stars: Rigel, Sirius, and Alford. (Fig. 8)

The cusped frames that al-Sahli created for the three major star pointers is particularly striking, in that it introduces in miniature forms that were used in the court arts and architecture of the Cordoban Umayyads, the ‘Amirids, and subsequently by the independent taifa kingdoms that emerged after 1031 in the wake of the dissolution of the Cordoban Umayyad caliphate.⁴⁸ For example, in the celebrated arcades of the reception hall at the Aljafería palace in Zaragoza.⁴⁹

The presence of these cusped arches, of this miniaturized architecture, as part of the visual language of the astrolabe might simply serve as a visual referent to the court settings, connecting this object to contemporary taifa court visual culture.⁵⁰ (Fig. 9) Yet, there are three other ways that we might interpret the presence of this heightened visual aesthetic on the face of the astrolabe. First, perhaps their inclusion in the visual program of this highly complex mathematical instrument is indicative of an intellectual appreciation for the mathematics that undergird these cusped and polylobed forms. In this sense the astrolabe’s rete recalls the first appearance of these forms in Umayyad Córdoba during the reign of the intellectual al-Hakam II, where they likewise gesture to mathematics, cognition and visual culture. Indeed, the polylobed and cusped arches and the ribbed domes of al-Hakam II’s expansion to the prayer hall, built between 960-65, may be symptomatic of what Felix Arnold has described as a new “mathematical turn” in architectural design, in which designers employed geometry to compose a “spatial web in which all parts are equal to each other and part of a single unified space.”⁵¹ (Fig. 10)

While the al-Sahli instrument preserved in Madrid is perhaps the most

spectacular of the early astrolabes from early al-Andalus, it is not the oldest. That distinction is held by an instrument preserved in the National Museum of Scotland, in Edinburgh.⁵² (Fig. 11). Made of cast brass, this astrolabe was made some forty years prior to the Madrid astrolabe. Measuring 15.5 cm in diameter, it is much smaller than the al-Sahli instrument preserved in Madrid. By contrast to the outsize dimensions of that astrolabe, this earlier instrument is sized to fit comfortably in the hand of the user. (Fig. 12) Like the others, the Edinburgh astrolabe features a carefully worked program of Kufic Arabic inscriptions, including the one prominently engraved on its rear face that names its maker and provides the time and place of its creation: “work of (*amala*) Muhammad ibn al-Saffar in Córdoba in the year 17 and 400 [417 AH/ 1026–1027 AD].” (Figs. 13-14)

The body (*mater*) of the astrolabe, its inscribed rim, and seven interchangeable plates housed within the mater are original, though the rete is a later medieval replacement.⁵³ (fig. 15) The interior of the mater is engraved with ecliptic coordinates, the ecliptic being a great circle on the celestial sphere representing the sun's apparent path during the year. The plates are inscribed with the latitudes and names of cities whose latitudes would have been appropriate for the use of that particular plate: these are San‘a and Mecca; Medina and Samarra; Kairouan and Córdoba; Zaragoza; Saba’ and Misr (Egypt); Qulsum and Tanja (Tangier); Toledo, and Constantinople. Each plate also provides the latitude for those cities, the hours in the longest day, azimuths (the direction of a celestial object from the observer), almucantars (a circle on the

celestial sphere parallel to the horizon), and lines indicating times of prayer. The choice of cities for which these plates were to be used offers some clues about the intended recipients and functions. They might reasonably be taken as an indicator of places that the end user might reasonably have been expected to travel to. The reasons for including plates suitable for Mecca and Medina, the two holy cities of Islam, is understandable, as these two cities were of course the goal of pilgrimage for any Muslim able to carry out the journey. The other cities represent important centers in the Iberian Peninsula and North Africa, or farther east.

Kairouan, in present-day Tunisia, and Córdoba – where the instrument was made -- were the two major political and intellectual centers of the Islamic west. Founded during the Umayyad conquest of North Africa in the eighth century, Kairouan developed into the premier religious, political, and cultural capital of Ifriqiyya under the Aghlabid dynasty (r. 800-909) and retained its importance long after.⁵⁴ Zaragoza was one of the major cities of al-Andalus from the eighth century.⁵⁵ Its flourishing intellectual reputation in the century in question was stimulated by the migration of Cordoban intellectuals to the city following the dissolution of the Cordoban Umayyad dynasty.⁵⁶ Toledo was likewise one of the earliest and most important of the independent taifa dynasties, ruled by the Dhu 'I-Nunid dynasty until the Castilian conquest in 1085.⁵⁷ The Dhu 'I-Nunid court was famous for its wealth and luxury. In the context of the present discussion, in the decades immediately following the construction of the astrolabe Toledo would be especially well known for its astronomers and other scientist-intellectuals, notably Ibn Sa'id, author of the medieval history of science the *Kitāb ṭabaqāt al-umam* (*Categories of Nations*), and the astronomer al-Zarkala.⁵⁸

At first glance the size and the visual language of Al-Saffar's astrolabe appear consistent with the earliest instruments made in the Abbasid east beginning in the eighth century.⁵⁹ However, analysis of Al-Saffar's astrolabe in Edinburgh indicates that the rete and part of its suspension device (throne), were not original to the instrument but rather later replacements. (Fig. 16) The difference in the coloration of the metal and the coarser workmanship, in comparison to the original body and plates, are apparent with the naked eye, but

scientific analysis of the astronomical calibration and the metallurgy confirm different phases of facture for the body and the rete. Astronomical analysis of the star positions on the rete suggest that it was probably made around 1320 AD (plus or minus 126 years).

Although we cannot know for certain what al-Saffar's original rete design looked like, a second instrument, preserved in Berlin and bearing a signature inscription identifying him as the maker, provides the best indication.⁶⁰ (Figs. 17-19) The inscription indicates that it was made in 1029-1030 in Toledo. Crafted only three years after Al-Saffar's Edinburgh instrument, its rete is original, thus offering the best sense of the Edinburgh instrument's original rete. (Fig. 20 While the Berlin instrument shows a heightened aesthetic impulse also evident in eastern astrolabes beginning in the tenth century, when considered in tandem with the other early Andalusí instruments, it nevertheless suggests an Iberian visual approach to astrolabe design that is distinct from the formal appearance of eastern examples.

Al-Saffar's Berlin instrument indicates that, instead of using the dagger-shaped star pointers typical of the earliest eastern instruments, he designed the slender, curving star pointers that al-Sahli likewise used in his instruments slightly later. The rete diverges in its formal visual language from the earlier eastern retes as we know them from instruments such as the elegant instrument signed by the celebrated instrument maker Khafif, likely made in the late ninth century.⁶¹ The oldest astrolabe preserved in the History of Science Museum in Oxford, it is a rare example of a fine precision instrument from Ibn Firnas's time

(Fig. 21) Made of brass and measuring 11.2 cm in diameter, on the front of its throne it is inscribed in a rounded nashkhi script with "by order of (*bi-rasm*) Ahmad al-Munajjim (the astronomer) of Sinjari" while the inscription on the back identifies the maker: "made by Khafif the apprentice (*ghulam*) of Ali ibn 'Isa."⁶²

Like Ibn Firnas, Khafif (active circa 875-900) was remembered by later intellectuals as an early instrument maker whose abilities were deemed worthy of mentioning in Arabic literary and scientific texts.⁶³ The tenth-century *Kitāb al-Fihrist* (*The Catalogue*) of Ibn al-Nadim, which is a key source on Abbasid literary culture, devotes a special section to Khafif, along with several other well-known "makers" of scientific instruments who moved in tenth-century court circles, including one father-daughter pair.⁶⁴ The text indicates that Khafif was connected, mainly as a teacher, to more than half of the sixteen ninth and tenth-century instrument makers that al-Nadim mentions in his work. The eleventh century distinguished Egyptian astronomer Ibn Yunus specifically mentions Khafif and his skill in astrolabe making; indeed, he asserted that Khafif's eminence as an astrolabe maker was comparable to Ptolemy's status in demonstrative sciences and to Galen's status in medicine.⁶⁵

These formal similarities between the rete decoration in the star pointers of both the Berlin and Madrid instruments suggest that by the early eleventh century a distinct Iberian visual language had been formulated, one which diverges from that used on the surviving instruments made in the Islamic east. It is interesting, therefore, that the designer of the fourteenth-century replacement rete emulates the early and eastern Islamic astrolabes, rather than those of

eleventh-century Iberia.⁶⁶

Signatures, makers and making

This brings us back to the signatures on the Madrid, Oxford, Edinburgh, and Berlin astrolabes, which provide further clues as to the connections between intellect, making, and visibility in early Islamic courts. Their importance to this discussion hinges on what we know about the identity and reputations of their makers. Historians of early Islamic art are usually frustrated by the lack of artisan's signatures, or any substantive information about those artisans whose signatures have survived. By contrast, we actually do know something about the identities of these early Andalusī astrolabe makers, thanks to the eminent Toledan scientist and intellectual Sa'īd Al-Andalusī (d. 1070), who flourished at the same moment.⁶⁷

Like other intellectuals of the time, he had studied law, religion, grammar, and literature, and was appointed the qadi of Toledo by that city's *taifa* ruler, Yahya ibn Dhi al-Nun. Later in his life he focused on the exact sciences, especially mathematics and astronomy, and divided his time between his legal duties, teaching, and research in the history of science, theology and literature. As a leading religious scholar as well as a scientist and intellectual, it may be that Sa'īd Al-Andalusī knew these astrolabe makers personally. In his famous Arabic treatise on the sciences and scientists of his time, the *Ṭabaqāt al-umam* (*Categories of Nations*) he tells us that the maker of the Edinburgh instrument, Muhammad al-Saffar, was "famous for his skill in building the astrolabe. No one before him, in al-Andalus, had known how to build this instrument better than

him.”⁶⁸ About al-Sahli, maker of the aforementioned instrument in Madrid, the same author has this to say:

During our present time, there are many young scholars who have distinguished themselves in the study of philosophy and demonstrated great energy and ability to acquire a knowledge of most of its branches. Those of them who live in Toledo or around it include...Ibrahim al-Sahli, the constructor of astrolabes.⁶⁹

That an intellectual as eminent as Sa‘id Al-Andalusi categorizes al-Sahli as a scholar who had distinguished himself in the branches of philosophy underscores the close relationship between high intellectual culture and the practices of design and making. Mathematics and astronomy were considered branches of philosophy in the ninth century, when ‘Abbas Ibn Firnas was carrying out his activities in the Cordoban court, as well as in the eleventh century when our chronicler Ibn Hayyan, the Toledan intellectual Sa‘id al-Andalusi, and our astrolabe makers Muhammad Ibn al-Saffar and Ibrahim al-Sahli, flourished.

While there are examples of ceramic and metalwork objects bearing signatures in early Islamic art, for the caliphal period we tend to know little about the artists, even when their names are painted or inscribed on the objects. Precision instruments that are also works of art, such as the astrolabes discussed above, are the major exception to this rule, in that they are very often signed by their makers.⁷⁰ The makers of such precision instruments may have enjoyed a prestige similar to that of calligraphers due to the intellectual expertise as well as the craft skill required to produce such objects.

A twelfth-century manuscript in the Qarawiyyin Library in Fes offers evidence that in al-Andalus artistic ability and social status were sometimes conjoined. The manuscript, copied after 1109 in Marrakesh, features beautiful calligraphy and the manuscript preserves the signature of the copyist, who was none other than a member of the royal family of Abbadid Seville, Abu Bakr Yahya Sharaf al-Dawla (d. after 1109).⁷¹ This prince was remembered in Arabic sources as an intellectual and a well-known book collector, who was also notable as a talented copyist and calligrapher.⁷² We might wonder whether this was merely hyperbole, or a literary convention or trope, but the evidence of the manuscript confirms the portrait of a royal who was also an intellectual with significant artistic skill as a calligrapher. Indeed, following this prince's exile to North Africa, he earned his living as a copyist and became the personal copyist for Ali ibn Yusuf ibn Tashfin (r. 1106-1143), the Almoravid ruler.

If we look at the Kufic style in which the signature inscription of the earliest instrument, the Edinburgh astrolabe, is inscribed, it appears distinct from the style used to inscribe the scientific information that makes up the bulk of the writing on the rear of the mater. Whereas the scientific information is written in a plain Kufic without any decoration, the letters of the signature inscription are embellished with pointed flag-like flourishes at the terminal points of individual letters. Although the difference between the treatment of the signature inscription and the scientific information is less apparent in al-Saffar's slightly later instrument, the inscription on his earlier work lends a greater visual importance to the name of the maker and to the place and time of the object's creation.

Al-Saffar employed the term *ʿamala* in his signature inscriptions on the instruments he made in Córdoba and Toledo, and this is the same term used in signature inscriptions from Umayyad Córdoba in the caliphal period. For example, on Cordoban ivories and also architectural inscriptions.⁷³ However, on al-Sahli's slightly later instruments he seems to have preferred the term *sanaʿa* over the earlier *ʿamala*. The same root (*s-n-ʿ*) is used to derive the noun, *saniʿ*, which is sometimes translated as “artisan,” but which I have translated as “maker,” following the lead of David A. King, who uses the term in his translation of Ibn al-Nadim's passage on famous instrument makers of the tenth century.⁷⁴ “Maker” also works well with recent attempts to broaden our understanding of how medieval works of architecture, visual, and material culture came into being.⁷⁵

That makers of fine instruments were recognized and held in esteem as intellectuals is not only suggested by the consistency, and the style, with which makers signed their instruments, it is also evident in key Arabic texts of the early medieval period. For example, the *Kitāb al-Fihrist* of Ibn al-Nadim, a key source on Abbasid literary culture, contains a section devoted to well-known makers of scientific instruments who moved in Abbasid-era court circles, including the aforementioned Khafif. As King has observed, Khafif was connected, mainly as a teacher, to more than half of the sixteen ninth- and tenth-century instrument makers that Ibn al-Nadim mentions in the *Fihrist*.⁴ Khafif's reputation among intellectuals was such that the eleventh-century distinguished Egyptian astronomer Ibn Yunus asserted, rather strikingly, that Khafif's eminence as an

astrolabe maker was comparable to that of Ptolemy, or to Galen's status in medicine.⁷⁶

It seems then that the designer-makers of these scientific instruments that are such striking works of art and visual culture were in some cases also highly regarded intellectuals who were recognized as expert scientific practitioners in their own time, and who were connected to, or themselves part of, elite learned and court circles. Leo Mayer, in his foundational book on Islamic astrolabists, observed as particularly worthy of note that the choice of phrases habitually inscribed on astrolabes along with the names of the instrument makers revealed an unusual pride in the work: for example phrases such as "among the objects skilfully made by [so and so]..." "[so and so]... constructed and invented it"; "[so and so]...calculated as well as constructed it himself."⁷⁷ Significantly, Mayer found that the vocabulary used in the astrolabe inscriptions is consistent with that normally used for literary work, for example "he composed," or "he wrote," whereas he found this was not the case for the inscriptions used on other types of Islamic metalwork objects.

The remains of an early thirteenth-century metalwork box, preserved in the David Collection in Copenhagen, offers further evidence to support a view of astronomers as makers of medieval visual culture. (Fig. 22) The fragment, measuring 4.4 cm high x 23.5 cm wide and 18.5 cm deep, is made of cast and hammered brass and beautifully inlaid with silver and copper.⁷⁸ Notably the lid of this metalwork box incorporates an early combination lock, of a type described by al-Jazari in his *Book of Knowledge of Ingenious Mechanical Devices*.⁷⁹ The box

features a signature inscription placed prominently front and center with the dials of the lock. This inscription, consisting of two lines and bisected by the large central roundel, reads: “Work of Muhammad ibn Hamid al-Asturlabi al-Isfahani in the year seven and ninety and five hundred [1200-1201 AD], and I tested it (?) (*fa-jarrabtuhu*).”⁸⁰ The signature inscription thus tells us that the maker of this finely crafted and technologically sophisticated locking box was a maker of astronomical instruments from Isfahan.⁸¹ Moreover, the reference the signature inscription to this astrolabe maker has having “tested” the mechanism himself, is suggestive perhaps of a kind of medieval “research and development” mindset, combined here with the design and craft processes. The lid’s locking mechanism consists of four double combination dials. Each of the dials can be set to 16 different positions, allowing for a staggering number of potential combinations - some four million. A movable dial and a larger concentric ring in which it is contained feature the characters for the possible combinations, inlaid in silver. Besides providing material evidence that astrolabe makers could and did craft other types of fine objects, the box predates al-Jazari’s treatise (written in 1206) and therefore allows us to situate al-Jazari within a broader context of craft practices and technology that existed by the thirteenth century. We should not see al-Jazari as a lone genius but rather see him as representative of broader practices uniting craft and intellect and which were already established in courts across the empire in the ninth century.

The passing down of astronomical and craft or technical knowledge within families was not limited to father and son. The aforementioned Ibn al-Nadim also

mentions a father and daughter among the famous instrument makers of his time: the father's name was al-ʿIjlī and the daughter was al-ʿIjlīyya.⁸² This female astrolabe maker, according to Ibn al-Nadīm, was an astronomer in the court of the famous Hamdanid ruler Sayf al-Dawla (d. 967), well known for cultivating a stellar circle of intellectuals at his court in Aleppo, including the great tenth-century philosopher al-Farabi (d. circa 961), whom medieval Arabic intellectuals considered second only to Aristotle.

Siblings too could be collaborators in this respect. The aforementioned Saʿīd Al-Andalusī, in his *Categories of Nations*, describes the brother of the aforementioned Cordoban astrolabe maker al-Saffar as an intellectual who was well known “for his precise knowledge of arithmetic, geometry, and astronomy,” who taught those subjects in Córdoba, presumably at the Great Mosque, and who is notable as the author of the earliest Andalusī treatise on the astrolabe.

Conclusion

As the pioneering instrument maker of al-Andalus and the leading intellectual of the ninth-century court, ʿAbbas Ibn Firnas's reputation -- when examined alongside the instruments and other works discussed above -- alerts us to close connections between science and medieval Islamic visual culture. Such works make clear the complex relationships between Islamic science and visual culture, in which aesthetic and intellectual agendas were linked through specific visual strategies.⁸³ Such strategies may have aided the users/viewers of scientific instruments and illustrated manuscripts in the acquisition of

knowledge.⁸⁴ Astrolabes, along with other fine scientific instruments such as globes, armillary spheres, and waterclocks, and illustrated scientific texts combined aesthetic as well as intellectual agendas that required their users to engage in a visual, physical, and mental process of close looking that led to intellectual understanding of complex scientific information.

‘Abbas Ibn Firnas’s reputation as the pioneering instrument maker, in tandem with the early fine instruments and other works of visual culture from al-Andalus and its neighbours, tell us that high social and/or intellectual status and the practices of design, making, and science were commensurable in medieval Islamic societies. Our polymath, and other intellectual-makers in al-Andalus and elsewhere, epitomize what Margaret Graves has described as a medieval Islamic “intellect of the hand.”⁸⁵ One final example of a surviving instrument, made later and in a different court context, illustrates the point. This is an astrolabe in the Metropolitan Museum of Art, whose inscription states that its maker was a prince of the Rasulid dynasty of thirteenth-century Yemen.⁸⁶ (Figs. 23-24) It suggests that sometimes even those with royal blood combined intellectual and craft skills: “This astrolabe is the work of ‘Umar ibn Yusuf ibn ‘Umar ibn ‘Ali ibn Rasul al-Muzaffari directly [by himself] and by his instruction in the year A.H. 690 [1291 A.D.].”

One might reasonably ask, given the royal identity of the named maker, whether in this case “maker” actually indicated the patron or intended recipient of the instrument, rather than the person who designed and/or fashioned the instrument. In fact, that does not seem to be the case here. Scholars have

pointed out that, besides the attestation of the maker's inscription on the instrument itself, a singular piece of written evidence exists to confirm the identity of its maker as the prince. This is a manuscript copy of a treatise on the construction of astrolabes, written in 'Umar Ibn Yusuf's own hand, and demonstrating his interest and technical knowledge in the subject matter.⁸⁷ Moreover, this manuscript also contains attestations from his teachers that the prince was in fact a competent maker of astrolabes, and the manuscript includes a description of the actual instrument preserved in the Metropolitan Museum. This Rasulid astrolabe and its accompanying manuscript treatise thus offers the clearest visual and material evidence that members of medieval Islamic intellectual and social elites were at times closely engaged in design and craft, and that such skills could be visibly demonstrated and acknowledged, and even celebrated, in medieval Islamic court societies.

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¹ Antonio R. Acedo del Olmo, *Abbas Ibn Firnās: El sabio de al-Andalus* (El Legado Andalusi, 2016); Julio Samsó, *The Oxford Encyclopedia of Philosophy, Science, and Technology in Islam* (Oxford, 2014), s.v. "'Abbās Ibn Firnās;" Mónica Rius, "El sabio total Ibn Firnās," *Jábega* 97 (2008), 9-13; M. Aragón Huerta, *Biblioteca de Al-Andalus* (Almería: Fundación Ibn Tufayl de Estudios Árabes, 2004), s.v. "Ibn Firnās, 'Abbas"; Elías Terés, "Sobre el vuelo de 'Abbas Ibn Firnās," *Al-Andalus* 29, 2 (1964): 365; Elías Terés, "'Abbas Ibn Firnās," in *The Formation of Al-Andalus*, 2 vols., ed. Manuela Marín, Maribel Fierro, and

Julio Samsó (Aldershot: Ashgate, 1998), 2:235–44; E. Lévi-Provençal, *Encyclopaedia of Islam*, Second Edition (Leiden, 2012) s.v. “‘Abbās b. Firnās.”

² Manuela Marín, “El «halcón Maltes» Del Arabismo Español: El Volumen II/1 de Al-Muqtabas de Ibn Hayyān,” *Al-Qanṭara: Revista de Estudios Árabes* 20, 2 (1999): 543–9. Also see J. Viguera Molins, “El manuscrito del Muqtabas II-1,” *Qurtuba: Revista de Estudios Andalusies* 2 (1997): 327–8.

³ See Joaquín Vallvé Bermejo’s introduction, *Al-Muqtabas II: Anales de Los Emires de Córdoba Alhaquém I...y Abderramán II...* Madrid, Spain: Real Academia de la Historia (Spain), 1999, ix–xii; Martínez Enamorado, “Ibn Hayyan, El Abanderado,” 30–34.

⁴ See Virgilio Martínez Enamorado, “Ibn Hayyan, El Abanderado de La Historia de Al

Ándalus,” *Jábega* 97 (2008): 30–4; Eduardo Manzano Moreno, “¿El fin de la historia? La historiografía árabe en torno al año 1000,” in *Hommes et sociétés dans l’Europe de l’An Mil*. Pierre Bonnassie, ed. Pierre Toubert (Presses Universitaires du Mirail, 2004), 407–19.

⁵ The manuscript is published in facsimile as Ibn Ḥayyān, *Muqtabas II: Anales*, 131r. The critical Spanish edition and translation is Ibn Ḥayyān, *Crónica de Los Emires Alḥakam I Y ‘Abdarrahmān II Entre Los Años 796 Y 847 (AlMuqtabas II-1)*, ed. Federico Corriente Serie Estudios Islámicos (Zaragoza: Instituto de Estudios Islámicos y del Oriente Próximo, 2001). The critical Arabic edition is Ibn Ḥayyān, *Al-Sifr Al-Thānī Min Kitāb Al-Muqtabas*, ed. Maḥmūd ‘Alī Makkī. Al-

Ṭab‘ah 1 (al-Riyāḍ: Markaz al-Malik Fayṣal lil-Buḥūth wa-al-Dirāsāt al-Islāmīyah, 2003).

⁶ The manuscript is copied on parchment and its pages measure 245 x 195 mm. On medieval manuscripts from the Islamic west see Umberto Bongianino, "Quelques Remarques Sur l'origine Des Écritures Coraniques Arrondies En al-Andalus (Ve/XIe-VIe/XIIe Siècles)," *Al-Qanṭara* 38, 2 (2017): 153–87; Umberto Bongianino, "The Origin and Development of Maghribī Round Scripts: Arabic Palaeography in the Islamic West (4th/10th-6th/12th Centuries)" (University of Oxford, 2017). Also see, by way of comparison with tenth-century examples, Mustapha Jaouhari, "Les Manuscrits Datés En Écriture Maghrébine: Enquete En Cours," *Fondation Max Van Berchem Bulletin*, 30 (2016): 3–5.

⁷ I am grateful to Umberto Bongianino for his observations and for drawing my attention to comparanda preserved in Moroccan and Italian collections. Personal communication, 2019.

⁸ Maqqarī, Aḥmad ibn Muḥammad, -1631 or 1632 and Reinhart Pieter Anne Dozy 1820–1883. *Analectes Sur l'histoire et La Littérature Des Arabes d'Espagne* (Amsterdam: Oriental Press, 1967); *Nafḥ Al-Ṭīb Min Ghuṣn Al-Andalus Al-Raṭīb*, ed. Iḥsān Abbās, Bayrūt, Dār Ṣādir, 1968.

⁹ Owen Jones's study on the Alhambra and his Alhambra court for the Crystal Palace Exhibition illustrate this fascination in nineteenth c. England, while Washington Irving's *Tales of the Alhambra* illustrate it in the American context. Owen Jones, *The Alhambra* (London: Saqi Books, 1997); Kathryn Ferry, "Owen Jones and the Alhambra Court at the Crystal Palace," in *Revisiting Al-Andalus:*

Perspectives on the Material Culture of Islamic Iberia and Beyond, ed. G. D. Anderson and M. Rosser-Owen, vol. 34, Medieval and Early Modern Iberian World (Leiden: Brill, 2007), 227–45.

Washington Irving, *The Alhambra*, Author's rev., ed. Irving (Washington), 1783–859. Works; v. 15 (New York: GP Putnam, 1851). For the problematic issues with “Moors” and “Moorish” see Ross Brann, “The Moors?,” *Medieval Encounters: Jewish, Christian and Muslim Culture in Confluence and Dialogue* 15, ii–iv (2009): 307–18; *Revisiting Al-Andalus: Perspectives on the Material Culture of Islamic Iberia and Beyond* (Leiden; Boston: Brill, 2007), 34.

¹⁰ Maqqarī, Aḥmad ibn Muḥammad, Pascual de Gayangos, and d. 1374 Ibn al-Khaṭīb. *The History of the Mohammedan Dynasties in Spain; Extracted from the Nafhu-t-Tib Min Ghosni-l-Andalusi-r-Rattīb Wa Tārīkh Lisānu-d-Dīn Ibni-l-Khattīb* (London, Printed for the Oriental Translation Fund of Great Britain and Ireland) 1840–3; New York, Johnson Reprint Corp. (1964): Johnson Reprint Corp., 1964.

¹¹ See the studies in Cristina Alvarez Millán and Claudia Heide, *Pascual de Gayangos: A Nineteenth-Century Spanish Arabist* (Edinburgh: Edinburgh University Press, 2008).

¹² There are many pages devoted to him in II-2 as well. Eight of the pages appear in *al-Muqtabas* 11-1, and 4 appear in the *al-Sifr al-Thani*. My thanks to Julio Samsó, personal communication.

¹³ On Ziryāb see Dwight F. Reynolds, “Ziryāb in the Aghlabid Court,” in *The Aghlabids and Their Neighbours: Art and Material Culture in 9th-Century North Africa*. Glaire D. Anderson, Corisande Fenwick, and Mariam Rosser-Owen, eds.

Leiden (Brill, 2017); Dwight F. Reynolds, "Al-Maqqarī's Ziryāb: The Making of a Myth," *Middle Eastern Literatures* 11, 2 (2008): 155–68; and Carl Davila, "Fixing a Misbegotten Biography: Ziryāb in the Mediterranean World," *Al-Masaq: Islam & the Medieval Mediterranean* 21, 2 (2009): 121–36. I would also like to thank Dwight Reynolds for generously sharing material from his study on Ziryāb, currently in preparation.

¹⁴ Ibn Ḥayyān, *Crónica de Los Emires Alḥakam I Y 'Abdarrahmān II*, pp. 137–42. This is the Spanish translation of Makkī's critical Arabic edition of Ibn Ḥayyān, *al-Muqtabis II-1*, published as Ibn Ḥayyān, *Al-Sifr Al-Thānī Min Kitāb Al-Muqtabas*. All translations by Stuart Sears.

¹⁵ Ibn Ḥayyān, *Crónica de Los Emires Alḥakam I Y 'Abdarrahmān II*, pp. 140–41.

¹⁶ S. Schechner Genuth, "Armillary Sphere," in *Instruments of Science: An Historical Encyclopedia*, eds. R. Bud & D. Warner (New York & London 1998), 28–31. On Andalusī science and instruments see Samsó, *Las ciencias de los antiguos*. For medieval Islamic instruments see King, *In Synchrony with the Heavens*. An Iberian painted manuscript from thirteenth century Toledo, the *Libros del Saber de Astronomía* (Book of Astronomical Knowledge) preserved today in the Complutense University, Madrid, provides an important perspective on Iberian scientific instrumentation in the court of Alfonso X (d. 1284), including descriptions and painted diagrams of an armillary sphere and other scientific instruments. See Laura Fernández Fernández, "Astrolabes on Parchment: The Astrolabes Depicted in Alfonso X's Libro Del Saber De Astrologia and Their Relationship to Contemporary Instruments," *Medieval Encounters* 23, 1–5

(2017): 287–310. The manuscript has been digitized by the Biblioteca

Complutense:

http://alfama.sim.ucm.es/dioscorides/consulta_libro.asp?ref=B18550071&idioma=0.

¹⁷ Farghānī, *On the Astrolabe*, translated by Richard Lorch (Franz Steiner Verlag, 2005), 23.

¹⁸ Al-Farghānī, *On the Astrolabe*, 25.

¹⁹ Shlomo Pines, "Philosophy, Mathematics and the Concepts of Space in the Middle Ages," in *Studies in Arabic Versions of Greek Texts and in Mediaeval Science*, Pines, Shlomo, 1908-1990. Works. 1979; v. 2 (Leiden: Brill, 1986), 75–90.

²⁰ Yaron Klein, "Imagination and Music: Takhyīl and the Production of Music in Al-Fārābī's Kitāb Al-Mūsīqī Al-Kabīr," In *Takhyīl: The Imaginary in Classical Arabic Poetics*, eds. Gelder, G. J. H. van, and Marlé Hammond (Cambridge, U.K.: Gibb Memorial Trust, 2008), 179–95. On al-Fārābī's discussion of "mixed" mathematics, also useful for these issues, see Gülru Necipoğlu, "Ornamental Geometries: A Persian Compendium at the Intersection of the Visual Arts and Mathematical Sciences," in *The Arts of Ornamental Geometry: A Persian Compendium on Similar and Complementary Interlocking Figures, Fī Tadākhul al-Ashkāl al-Mutashābiha Aw al-Mutāwāfiqa* (Bibliothèque Nationale de France, Ms. Persan 169, Fols. 180r-199r): A Volume Commemorating Alpay Özdural, Muqarnas, Supplements ; Volume XIII (Leiden; Boston: Brill, 2016), 20.

²¹ Emphasis mine.

²² Valérie Gonzalez, *Beauty and Islam: Aesthetics in Islamic Art and Architecture* (London: I.B. Tauris, 2001).

²³ Ibn Ḥayyān, *Crónica de Los Emires Alḥakam I Y ‘Abdarraḥmān II*, pp. 137-42.

²⁴ Translator’s note, "predict the future from the stars, astrology."

²⁵ Transl. Stuart Sears. Ibn Ḥayyān, *Al-Sifr Al-Thānī Min Kitāb Al-Muqtabas*, ed. Makkī, Al-Ṭab‘ah 1. al-Riyāḍ: Markaz al-Malik Fayṣal lil-Buḥūth wa-al-Dirāsāt al-Islāmīyah (2003), 347–50.

²⁶ Ibn Ḥayyān, *Crónica de Los Emires Alḥakam I Y ‘Abdarraḥmān II Entre Los Años 796 Y 847 (Almuqtabis II-1)*, pp. 140-41.

²⁷ According to Julio Samsó, Ptolemy’s “Handy Tables,” later revised by Theon of Alexandria. Personal communication.

²⁸ Ibn Ḥayyān, *Crónica de Los Emires Alḥakam I Y ‘Abdarraḥmān II*, pp. 140-41.

³⁰ Donald R. Hill, *Arabic Water-Clocks*, Maṣādir Wa-Dirāsāt Fī Tārīkh al-‘ulūm al-‘Arabīyah al-Islāmīyah. Silsilat Tārīkh al-Tiknūlūjiyā 4 (Aleppo, Syria: University of Aleppo, Institute for the History of Arabic Science, 1981). The earliest extant Islamic waterclock that still survives is the Merinid clock constructed in 1357 over the portal of the Bu Inaniyya madrasa in Fes.

³¹ Hill, *Arabic Water-Clocks*.

³² Aḥmad Ḥasan and Donald Routledge Hill, *Islamic Technology: An Illustrated History* (New York: Cambridge University Press, 1986), 55–7; Donald Hill, “Andalusian Technology,” in *Studies in Medieval Islamic Technology: From Philo*

to *Al-Jazarī, from Alexandria to Diyār Bakr*, ed. David A. King (Aldershot: Ashgate, 1998), XVIII/1–16.

³³ Ibn Ḥayyān, *Crónica de Los Emires Alḥakam I Y ‘Abdarrahmān II*, pp. 140–41.

³⁴ My thanks to Kirsty Stewart and Foteini Spingou for drawing my attention to Byzantine epigrams as a possible point of comparison. The point lies beyond the scope of this book but would be interesting to research further. See for example Ivan Drpić, *Epigram, Art, and Devotion in Later Byzantium* (Cambridge, United Kingdom: Cambridge University Press, 2016).

³⁵ On the notion of Islamic "speaking" objects see for instance Avinoam Shalem, "If Objects Could Speak," in *The Aura of Alif: The Art of Writing in Islam*, ed. Jürgen Wasim Frembgen (Munich: Prestel, 2010), 127–47; Hana Taragan, "The 'Speaking' Inkwell from Khurasan: Object as 'World' in Iranian Medieval Metalwork," *Muqarnas* 22, 1 (January 1, 2005): 29–44.

³⁶ Olga Bush, "Poetic Inscriptions and Gift Exchange in the Medieval Islamicate World," *Gesta* 56, 2 (2017): 179–97; *ibid.*, "Prosopopeia: Performing the Reciprocal Gaze," *Muqarnas Online* 32, 1 (2015): 13–9. For an overview of the pyxis and the Cordoban ivories see Glaire Anderson and Mariam Rosser-Owen, "Great Ladies and Noble Daughters: Ivories and Women in the Umayyad Court at Córdoba," in *Pearls on a String: Art in the Age of Great Islamic Empires*, ed. Amy Landau (University of Washington Press, 2015), 28–51.

³⁷ Translation by Dr Afifi al-Akiti, 2010. Inv. 48213. Oxford History of Science Museum. King, *In Synchrony with the Heavens II*: 66–68; on al-Bīrūnī's

description of a similar type of device see Donald R. Hill, "Al-Bīrūnī's Mechanical Calendar," *Annals of Science* 42, 2 (March 1985): 139–63.

³⁸ British Museum Inv. No. ME OA 1888.5-26.1. Francesca Leoni, *Power and Protection: Islamic Art and the Supernatural* (Oxford: Ashmolean Museum, 2016); Emilie Savage-Smith and Marion B. Smith, "Islamic Geomancy and a Thirteenth-Century Divinatory Device: Another Look," in *Magic and Divination in Early Islam/ Edited by Emilie Savage-Smith* (Ashgate, 2004), 211–76; Emilie Savage-Smith and Marion B. (Marion Bush) Smith, *Islamic Geomancy and a Thirteenth-Century Divinatory Device* (Malibu: Undena Publications, 1980). On geomancy and divination see Pierre Lory, "Divination & Religion in Islamic Medieval Culture," in *Power and Protection: Islamic Art and the Supernatural* (Oxford: Ashmolean Museum, 2016), 13–32; Emilie Savage-Smith, "Magic and Divination in Early Islam," in *Magic and Divination in Early Islam/ Edited by Emilie Savage-Smith* (Ashgate, 2004), xiii–li; Emilie Savage-Smith, "Divination," in *Science, Tools & magic. Part One. Body and Spirit, Mapping the Universe. By Francis Maddison and Emilie Savage-Smith* (Nour Foundation, in association with Azimuth Editions and Oxford University Press, 1997), 148–59.

³⁹ On medieval Iberian astrolabes see Salvador García Franco, *Catálogo Crítico de Astrolabios Existentes En España* (Instituto Histórico de Marina: Madrid, 1945); but especially Azucena Hernández Pérez, *Catálogo razonado de los astrolabios de la España medieval* (Madrid: La Ergástula, 2018), which updates the previous literature on the instruments in question, providing a complete catalogue and study of the instruments; also see by the same author "Astrolabios

Andalusíes e Hispanos: De La Precisión a La Suntuosidad*/Andalusi and Hispanic Astrolabes: From Precision to Sumptuousness" (Universidad Complutense de Madrid, 2017); *ibid.*, "Astrolabios Andalusíes E Hispanos: De La Precisión a La Suntuosidad*/Andalusi and Hispanic Astrolabes: From Precision to Sumptuousness," *Anales De Historia Del Arte* 24 (2014): 289–305; *ibid.*, "El dragón en el astrolabio," *Revista Digital de Iconografía Medieval* 7, 13 (2015): 19–31; *ibid.*, "Astrolabes for the King: The Astrolabe of Petrus Raimundi of Barcelona," *Medieval Encounters* 23, 1–5 (September 22, 2017): 421–43.

⁴⁰ Azucena Hernández Pérez, "Arte y ciencia en Al-Andalus: el astrolabio nazarí de Alcalá la Real," *Boletín del Instituto de Estudios Giennenses*, 215 (2017): 259–84, see the map of their geographic distribution on p. 260. I will not discuss the medieval drawing of the astrolabe preserved in Paris BN MS lat 7412, which Kunitschz ascribed to al-Andalus circa 1000 and which Hernández includes as the earliest in the list of Andalusi Umayyad astrolabes, as it does not bear an inscription identifying its maker, date, or place of facture. See Hernández, *Catálogo razonado*; Paul Kunitzsch, Menso Folkerts, and Richard Lorch, *Sic Itur Ad Astra: Studien Zur Geschichte Der Mathematik Und Naturwissenschaften: Festschrift Für Den Arabisten Paul Kunitzsch Zum 70. Geburtstag* (Wiesbaden: Harrassowitz, 2000), 185.

⁴¹ Besides the publications in the previous notes, see the essays in the special issue of *Medieval Encounters* 23, 1–5 (September 22, 2017), including Silke Ackermann, "Introduction Hic Sunt Dracones—Astrolabe Research Revisited," *Medieval Encounters* 23, 1–5 (September 22, 2017): 3–7. Gunther, R, and

William H. (William Hook) Morley, *The Astrolabes of the World: Based upon the Series of Instruments in the Lewis Evans Collection in the Old Ashmolean Museum at Oxford: With Notes on Astrolables in the Collections of the British Museum, Science Museum, Sir J. Findlay, Mr. S. V. Hoffman, the Mensing Collection, and in Other Public and Private Collections* (London: Holland Press, 1976).

⁴² Mayer, L. A., *Islamic Astrolabists and Their Works* (Genève: A. Kundig, 1956); Also see Mayer, L. A. "Islamic Astrolabists: Some New Material," in *Aus Der Welt Der Islamischen Kunst: Festschrift Für Ernst Kühnel Zum 75. Geburtstag Am 26.10.1957*. Hrsg. Richard Ettinghausen, 293–96. Mann, 1959.

⁴³ Savage-Smith, "The Most Authoritative Copy," 128.

⁴⁴ Kunitzsch et al., 185.

⁴⁵ MAN Madrid, Inv. No. 50762. On the maker and the instrument's bibliography see Hernández Pérez, *Astrolabios en al-Andalus y los reinos medievales hispanos*, 70; 98–9, A6; *ibid.*, *Catálogo razonado de los astrolabios de la España medieval*, 71–80; Mercé Viladrich, *El legado científico andalusí*, 64.

⁴⁶ A much smaller astrolabe preserved in the Museum of the History of Science, Oxford bears an inscription that identifies it as the work of the same maker, Ibrahim ibn Sa'īd al-Sahli. This is Oxford MHS Inv. 55331. It is sized to be comfortably held in the hand of a user, but despite its comparatively diminutive dimensions, the heightened visual elaboration of its rete further attests to the maker's virtuosity in creating instruments that are both works of art and works of science. Like its much larger counterpart, this instrument offers the viewer the

same impression of carefully worked mathematical precision coupled with a luxurious sense of materiality and design. On the maker and overview of the bibliography see Hernández Pérez, *Astrolabios en al-Andalus y los reinos medievales hispanos*, 70; illustrated on p. 98, A7; see also *ibid.*, p. 98, A8 a third astrolabe by the same maker, whose signature inscription indicates it was made in Valencia in 463AH/1071 AD, and which is preserved in the Astronomical Observatory, Rome (Inv. Number 157/688).

⁴⁷ Hernández Pérez, *Astrolabios en al-Andalus y los reinos medievales hispanos*, 70; illustrated on p. 99.

⁴⁸ On cusped arches in the ‘Amirid context see Mariam Rosser-Owen, “Poems in Stone: The Iconography of ‘āmirid Poetry, and Its ‘Petrification’ on ‘āmirid Marbles,” *Revisiting Al-Andalus: Perspectives on the Material Culture of Islamic Iberia and beyond*, ed. Glaire D. Anderson and Mariam Rosser-Owen (2007), 83–98. Also see Rosser-Owen’s forthcoming book on the ‘Amirids.

⁴⁹ On this monument see Gonzalo M. Borrás Gualis and Bernabé Cabañero Subiza, *La Aljafería y el arte del Islam Occidental en el siglo XI. Actas del Seminario Internacional celebrado en Zaragoza los días 1, 2 y 3 de diciembre de 2004. Coords. Gonzalo M. Borrás Gualis, Bernabé Caballero Subiza* (Institución “Fernando el Católico,” 2012); Bernabé Cabañero Subiza, *El Salón Dorado de la Aljafería: ensayo de reconstitución formal e interpretación simbólica*, 1a ed., Conocer Alandalús; 1 (Zaragoza: Instituto de Estudios Islámicos y del Oriente Próximo, 2004); Cynthia Robinson, *In Praise of Song: The Making of Courtly Culture in al-Andalus and Provence, 1005-1134 A.D.* (Leiden: Brill, 2002); *ibid.*,

“The Aljafería in Saragossa and Taifa Spaces,” in *The Literature of Al-Andalus*, ed. María Rosa Menocal, Raymond P. Scheindlin, Michael Sells (Cambridge University Press, 2000), 233–4; Dorothea Duda, Gisela Kircher, and Christian Ewert, *Islamische Funde in Balaguer Und Die Aljafería in Zaragoza*, Madrider Forschungen; Bd.7. (Berlin: De Gruyter, 1971).

⁵⁰ On miniaturization of architecture on objects see Margaret Graves, *Arts of Allusion: Object, Ornament, and Architecture in Medieval Islam* (Oxford: Oxford University Press, 2018), 13-22.

⁵¹ On the decorative motifs of Iberian astrolabes and their relation to architectural forms, see Hernández Pérez, *Astrolabios en al-Andalus y los reinos medievales hispanos*, 183–6. On the mathematical turn see Felix Arnold. “Mathematics and the Islamic Architecture of Córdoba,” *Arts* 7, 3 (2018): 35.

⁵² I would like to thank Tacye Phillipson for generously providing access to the object and its file. On the astrolabe see Hernández Pérez, *Astrolabios en al-Andalus y los reinos medievales hispanos*, 68–70; 96–7, A3; *ibid.*, *Catálogo razonado de los astrolabios de la España medieval*, 43–50; Mercé Viladrich, *El legado científico andalusí*, 63–4; Angus MacDonald et al., *A Heavenly Library: Treasures from the Royal Observatory’s Crawford Collection: An Exhibition Held at the National Museums of Scotland, Chambers Street, Edinburgh, 8 October-31 December 1994* (Edinburgh: Royal Observatory, Edinburgh, 1994), 24; David A. King, “Some Medieval Astronomical Instruments and their Secrets,” in *Non-Verbal Communication in Science prior to 1900*, ed. Mazzolini, R. G. (Florence 1993), 29–52.

⁵³ On the rete see David A. King, "Medieval Astronomical Instruments: A Catalogue in Preparation," *Bulletin of the Scientific Instrument Society* 31 (1991), 3–7 and

Francis Maddison and Anthony Turner, "Catalogue: Science and Technology In Islam: An International Loan Exhibition, held in the Science Museum, London 6 April – 31 August 1976, as part of the World of Islam Festival" (corrected typescript in NMS object file), 104–5.

⁵⁴ See the essays in *The Aghlabids and Their Neighbours: Art and Material Culture in Ninth-Century North Africa*, eds. Anderson, Glaire D., Corisande Fenwick, and Mariam Rosser-Owen (Leiden: Brill, 2017).

⁵⁵ On taifa arts and court culture see the work of Cynthia Robinson cited above, and also "Arts of the Taifa Kingdoms," in *Al-Andalus: The Art of Islamic Spain*, ed. Jerrilynn Denise Dodds (New York: Metropolitan Museum of Art: Distributed by HNAbrams, 1992), 49–61.

⁵⁶ M.J. Viguera, "Saraḡuṣṭa," in *Encyclopaedia of Islam, Second Edition*, ed. P. Bearman, Th. Bianquis, C.E. Bosworth, E. van Donzel, W.P. Heinrichs. Consulted online on 05 November 2018

<http://dx.doi.org.ezproxy.is.ed.ac.uk/10.1163/1573-3912_islam_SIM_6621>

⁵⁷ On the city in the Umayyad and taifa periods see María Grego Gómez, *Toledo en la época Omeya (ss. VIII-X)* (Toledo: Diputación Provincial de Toledo, 2007); Clara Delgado Valero, *Regreso a Tulaytula: Guía Del Toledo Islámico: Siglos VIII-XI*, Conocer Castilla-La Mancha; 23 (Toledo: Junta de Comunidades de Castilla-La Mancha, 1999). On the taifa rulers see D.M. Dunlop, "Dhu 'l-Nūnids,"

in *Encyclopaedia of Islam, Second Edition*, ed. P. Bearman, Th. Bianquis, C.E.

Bosworth, E. van Donzel, W.P. Heinrichs.

⁵⁸ Dunlop, D.M., "Dhu 'l-Nūnids."

⁵⁹ On the oldest Islamic astrolabe, made of brass and measuring 8.5 cm see King, *Instruments of Mass Calculation*, 422–33.

⁶⁰ Staatsbibliothek Zu Berlin - Preussischer Kulturbesitz, Orientabteilung, Sprenger 2050. On the maker and bibliography for the instrument see Hernández Pérez, *Astrolabios en al-Andalus y los reinos medievales hispanos*, 70; 96–7, A4; *ibid.*, *Catálogo razonado*, 51–8; Viladrich, *El legado científico andalusí*, 64.

⁶¹ Formerly in Baghdad, but whereabouts now unknown. See King, *Instruments of Mass Calculation*, 422ff.

⁶² MHS, Oxford. Inv. 47632. King, *In synchrony with the heavens* II: 1005.

⁶³ King, *In synchrony with the heavens* II: 414, 418.

⁶⁴ See King's translation and commentary on his text on astrolabe makers in, *In synchrony with the heavens* II: 453–4.

⁶⁵ See translation and commentary of his text in King, *In synchrony with the heavens* II: 455–6.

⁶⁶ This is evident in the use of the simple dagger-shaped star pointers, rather than the slender elegant curves that distinguish the eleventh-century Iberian instruments. How the fourteenth-century designer came to be aware of the visual conventions of the early eastern astrolabes and why they chose to evoke those, rather than the distinct visual forms shared among the eleventh-century Iberian

astrolabes are fascinating questions, but ones which require further research and lie beyond the boundaries of this study

⁶⁷ On Ṣāʿid Al-Andalusī's background and reputation see Jaako Hämeen-Anttila, "Ṣāʿid Al-Andalusī, His System of Nations and the Progress of Science,"

Zeitschrift Für Geschichte Der Arabisch-Islamischen Wissenschaften / Majallat Tārīkh Al-ʿUlūm Al-ʿArabīyah Wa ʿl-Islāmīyah 19 (2011 2010): 2–4. My thanks to Professor Hämeen-Anttila for drawing my attention to this essay.

⁶⁸ "Il avait un frère nommé Muhammad, célèbre par son habileté dans la construction de l'astrolabe. Nul avant lui, en Andalousie, n'avait su mieux que lui construire cet instrument," *Kitāb Ṭabaqāt Al-umam*. Translated by Régis Blachère. *Manshūrāt Mahad Tārīkh Al-Ulūm Al-Arabīyah Wa-al-Islāmīyah*. Falsafah Al-Islāmīyah; 1. Frankfurt Am Main: Institute for the History of Arabic-Islamic Science at the Johann Wolfgang Goethe University, 1999, p. 131 of the French translation/ p. 70 of the Arabic text.

⁶⁹ English translation, *Science in the Medieval World*, 69, though the French translation is preferred: 'D'ailleurs, à l'heure actuelle, il existe de jeune savants qui, ça et là, étudient avec zèle la philosophie, dont l'entendement est sûr, les idées nobles, et qui ont déjà acquis la connaissance des diverses parties de cette science... De ce nombre, parmi ceux qui résident à Tolède ou dans les environs, citons: ... Ibrahīm ibn Saʿīd as-Sahlī, le Constructeur d'astrolabes [al-Asturlabi],’ *Kitāb Ṭabaqāt Al-umam*, 138–9/ 75 of the Arabic text.

⁷⁰ See Mayer, *Islamic Astrolabists and Their Works* and *ibid.*, *Islamic Metalworkers and Their Works* (Geneva, A. Kundig, 1959).

⁷¹ Khizānat al-Qarawiyyīn - Fes, mss. 605/1-2, discussed in Umberto Bongianino, "The Origin and Development of Maghribī Round Scripts: Arabic Palaeography in the Islamic West (4th/10th-6th/12th Centuries)" (PhD thesis, University of Oxford, 2017) I:70; 132 and II: 120-121 (item 39). Also see *Le Maroc médiéval: un empire de l'Afrique à l'Espagne: album de l'exposition* (Paris: Musée du Louvre: Hazan, 2014), 226, No. 129. My thanks to Bongianino for bringing the manuscript and its calligrapher to my attention.

⁷² Aḥmad ibn Muḥammad Maqqarī, *Nafḥ Al-Ṭīb Min Ghuṣn al-Andalus al-Raṭīb*, ed. Iḥsān Abbās (Bayrūt: Dār Ṣādir, 1968), IV: 96, cited in Bongianino, "The Origin and Development of Maghribī Round Scripts," I: 70.

⁷³ Sheila S. Blair, "What the Inscriptions Tell Us: Text and Message on the Ivories from Al-Andalus," *Journal of the David Collection* 2, 1 (2005): 74–99.

⁷⁴ King, *Instruments of Mass*. Also see Yves Porter, "Les Art et Les Sciences: Ars Gratia Ars," in *L'âge d'or Des Sciences Arabes: Exposition Présentée à l'Institut Du Monde Arabe, Paris, 25 Octobre 2005-19 Mars 2006*. 1er éd. Arles: Actes sud, 2005, 243.

For the occurrence of the term in the Geniza documents see S. D. Goitein and Gustave E. von Grunebaum, *A Mediterranean Society; the Jewish Communities of the Arab World as Portrayed in the Documents of the Cairo Geniza*. 1999 paperback edition (Berkeley, University of California Press, 1967–1993: University of California Press, 1967, 6 vols. I), 93, 410, 414, 415, 418; II, 478.

⁷⁵ *Reassessing the Roles of Women as "makers" of Medieval Art and Architecture*, ed. Therese Martin (Leiden: Brill, 2012).

⁷⁶ King, *Instruments of Mass Calculation*.

⁷⁷ Mayer, *Islamic Astrolabists*.

⁷⁸ David Collection, Inv. Number 1/1984. I would like to thank Joachim Meyer of the David Collection for his assistance. For overview and bibliography see *L'âge d'or des sciences arabes*, catalogue number 151, p. 277.

⁷⁹ Julian Raby, ed., "Al-Jazarī's Combination Lock: Two Contemporary Examples," in *The Art of Syria and the Jazīra, 1100-1250*, Oxford Studies in Islamic Art 1 (Oxford: Oxford University Press, 1985), 141–57.

⁸⁰ The perimeter inscription states, "Glory and prosperity and wealth and happiness and well-being and [God's] support and success and power and strength and mercy and tranquility ... health and grace and happiness and well-being and [God's] support and success and power and strength and gratitude and tranquillity." Translated by Will Kwiatkovsky, courtesy of the David Collection.

⁸¹ Savage-Smith, "The Most Authoritative Copy of 'Abd Al-Rahman Al-Ṣūfī's Tenth-Century Guide to the Constellations," 128.

⁸² On the daughter and father see King, *In Synchrony with the Heavens* II: 455. On examples in al-Andalus with overview of the sources see Hernández Pérez, *Astrolabios en al-Andalus y los reinos medievales hispanos*, 163–6. Maribel Fierro suggested that her name indicates enslaved or freed status. Personal communication.

⁸³ Persis Berlekamp, "Visible Art, Invisible Knowledge," *International Journal of Middle East Studies* 45, 3 (August 2013): 563–5.

⁸⁴ On the role of artisans and their activities in the production of knowledge and the emergence of the European Scientific Revolution see Pamela O. Long, *Openness, Secrecy, Authorship: Technical Arts and the Culture of Knowledge from Antiquity to the Renaissance*, Johns Hopkins paperbacks edition (Baltimore: Johns Hopkins University Press, 2004); Pamela H. Smith, *The Body of the Artisan: Art and Experience in the Scientific Revolution* (Chicago: University of Chicago Press, 2004). Thanks to Jill Burke for bringing this work to my attention.

⁸⁵ Graves, *Arts of Allusion*, 26–58.

⁸⁶ David A. King, *Islamic Astronomy and Geography* (Farnham, England: Ashgate, 2012) 156; Maryam Ekhtiar, Sheila R. Canby, Navina Haidar, and Priscilla P. Soucek, ed. *Masterpieces from the Department of Islamic Art in The Metropolitan Museum of Art* (New York: The Metropolitan Museum of Art, 2011) no. 107, 158–59; *L'Age d'Or des Sciences Arabes* (Paris: Institut du Monde Arabe, 2005) no. 26, 98–99; The Metropolitan Museum of Art, Daniel S. Walker, Arturo Ponce Guadián, Sussan Babaie, Stefano Carboni, Aimee Froom, Marie Lukens Swietochowski, Tomoko Masuya, Annie Christine Daskalakis-Matthews, Abdallah Kahil, and Rochelle Kessler. "Colegio de San Ildefonso, Septiembre de 1994–Enero de 1995." In *Arte Islámico del Museo Metropolitano de Arte de Nueva York* (Mexico City: Consejo Nacional para la Cultura y las Artes, 1994) 81, 206–7; "Masterpieces from The Metropolitan Museum of Art New York." in *The Arts of Islam* (Berlin, 1981) no. 56, 146–47; "Specimens of Mohammedan Art in the Metropolitan Museum of Art." *Metropolitan Museum Studies* 1, 1 (November 1928), 107.

⁸⁷ This manuscript was apparently one of several scientific treatises that this prince compiled. See note 86.